



## Validation of long-range scanning lidars deployed around the Høvsøre Test Station

Lea, Guillaume; Courtney, Michael

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# Validation of long-range scanning lidars deployed around the Høvsøre Test Station

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Guillaume Lea and Michael S. Courtney

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**Authors:** Guillaume Lea and Michael S. Courtney

**Title:** Validation of long-range scanning lidars deployed around the Høvsøre Test Station

**Department:** DTU Wind Energy, Risø Campus

**Summary (max 2000 characters):**

This report describes validation tests performed on the long-range scanning lidars prior to deployment in the RUNE campaign. Position and speed accuracy tests have been performed at a range of 5 km from the Høvsøre met mast. This range is typical of ranges for near-coastal resource measurements. The accuracy of the beam positioning was checked by comparing the predicted position to the position found from hard-target returns from the mast. Radial speeds measured by the lidar were also found to be in close agreement with the mast measured wind speeds projected in the line of sight direction.

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**Danmarks Tekniske Universitet**

DTU Vindenergi  
Nils Koppels Allé  
Bygning 403  
2800 Kgs. Lyngby  
Telephone

[www.vindenergi.dtu.dk](http://www.vindenergi.dtu.dk)

# Preface

This report encompasses deliverable D1.3 of the ForskEL project RUNE (Reducing uncertainty of near-shore wind resource estimates using onshore lidars).

DTU, Risø Campus, October 2016

Guillaume Lea & Michael S. Courtney

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## Summary

This report describes validation tests performed on the long-range scanning lidars prior to deployment in the RUNE campaign. Position and speed accuracy tests have been performed at a range of 5km from the Høvsøre met mast. This range is typical of ranges for near-coastal resource measurements. The accuracy of the beam positioning was checked by comparing the predicted position to the position found from hard-target returns from the mast. Radial speeds measured by the lidar were also found to be in close agreement with the mast measured wind speeds projected in the line of sight direction.

# 1. Introduction

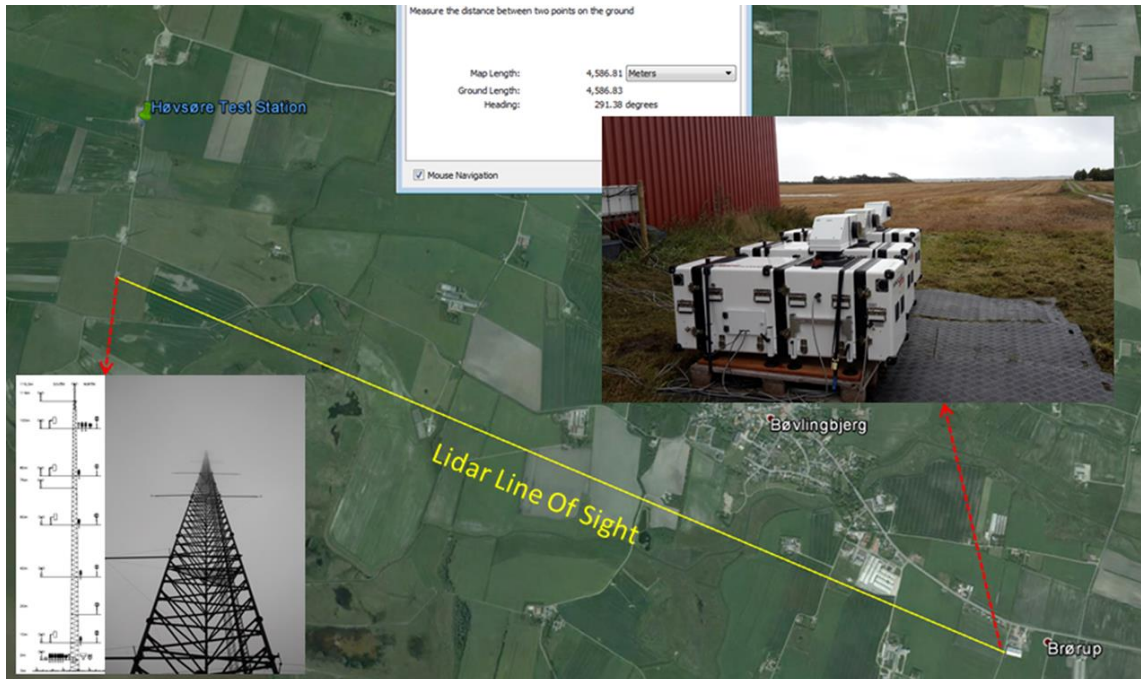
RUNE (**R**educing the **U**ncertainty of **N**ear-shore **E**nergy estimates) aims to determine how and by how much scanning lidars placed on the coast can improve estimates of the available near-shore wind resource. Technical and logistical aspects of coastal lidar deployments are explored in [1] and an investigation of the relative merits of 1 or 2 scanning lidars is reported in [2]. The actual measurement campaign conducted with a number of profiling and scanning lidars is reported in [3].

Before the RENE campaign, all lidars (profilers and scanning lidars) have been deployed around the Høvsøre test station for 3 weeks in order to assess the measurement quality. Profilers were installed around the 116-m meteorological mast for direct inter-comparison. Scanning lidars were deployed approximately 5 km away from the same mast, programmed to stare at the mast-top cup anemometer in order to assess the measurement quality at a distance of interest similar to the following RENE layout.

This report aims at describing the line-of-sight (LOS) calibration method applied to the scanning lidars by taking data of one of the 3 scanning lidars (WLS200S) for comparison. The methodology used generally follows that used to calibrate nacelle lidars and described in [4]. Unfortunately, during this deployment, two of the scanning lidars became unserviceable, We are therefore only able to present results from one lidar (Sterenn) but believe that the results obtained are indicative of the general level of uncertainty that can be achieved.

## 2. Deployment and Alignment

All 3 WLS200Ss were deployed close to each other at GPS position: 56°25'32.07"N, 8°13'12.52"E, as shown in [Figure 1](#)~~Figure 4~~. From this position there is a clear view of the Høvsøre 116.5-m met mast in the direction 290° and at a distance of 4.6 km. The prevailing winds at Høvsøre are from the SW and W. Such winds result in a negative radial wind speed component in the LOS direction. This will be typical of winds measured in a west-coast near-shore deployment in Denmark.



**Figure 1** The pre-RUNE long range windScanner deployment

For local alignment, 5 targets were selected (flag poles) or manually deployed (sticks), as shown in [Figure 2](#)~~Figure 2~~. These are used to calibrate the scanner heads positioning offsets by comparing a Leica multi-station theodolite results to the positions given by the scanner head encoders after finding the target using the “CNR Mapper” tools provided by the Master Computer software. More details on CNR Mapping technique are given in RUNE Report 1.4.





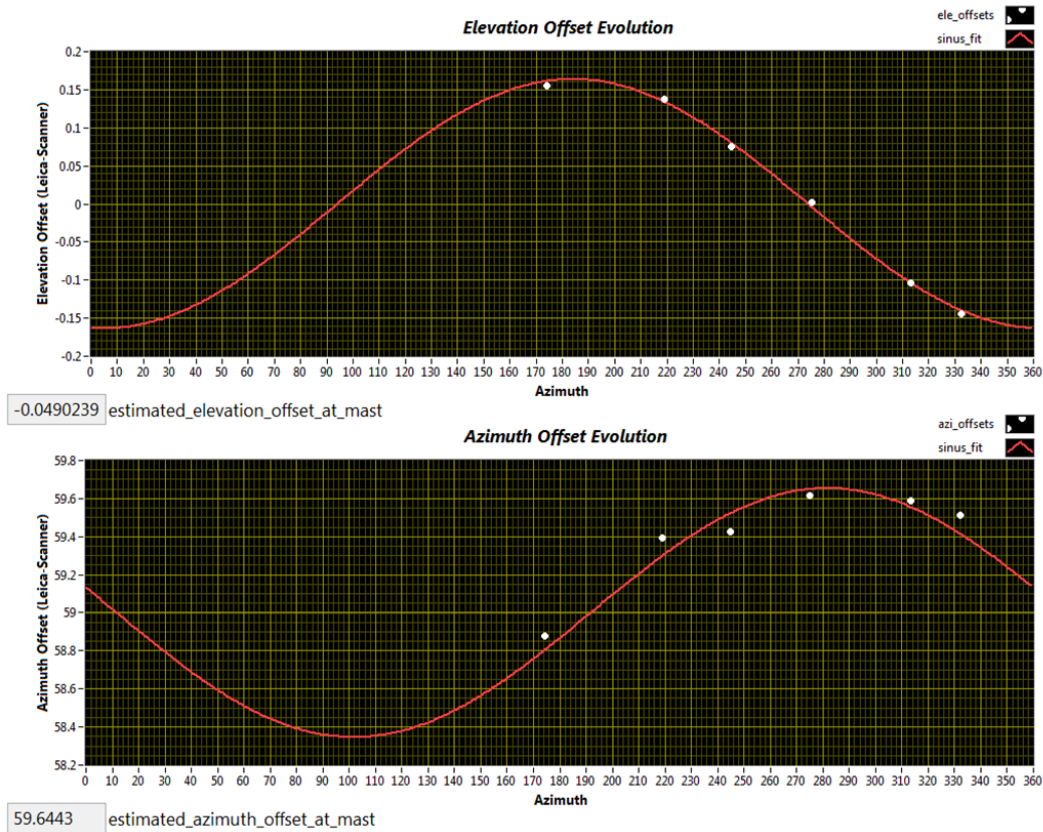
**Figure 2 pre-Rune WLS200S (Sterenn) and surrounding targets layout**

Each target backscatters the light emitted from both Theodolite and Lidars at a precise pair of azimuth and elevation angles. The difference between the angles determined from the scanner and the Leica (deemed to be the scanner offset) are given in the table below for each of the six targets.

**Table 1 Results of hard targets mapping from Leica theodolite and the Sterenn scanning lidar**

Target	Azimuth			Elevation		
	Leica	Scanner	Offset	Leica	Scanner	Offset
FP1	332.236	-87.275	<b>419.511</b>	2.580	2.725	<b>-0.145</b>
FP3	313.213	-106.375	<b>419.588</b>	1.021	1.125	<b>-0.104</b>
FP4	275.158	-144.460	<b>419.618</b>	1.001	1.000	<b>0.001</b>
FP5	219.146	-200.250	<b>419.396</b>	2.088	1.950	<b>0.138</b>
S1	244.775	-174.650	<b>419.425</b>	0.025	-0.050	<b>0.075</b>
S2	174.236	-244.640	<b>418.876</b>	0.356	0.200	<b>0.156</b>

The final offsets are plotted in [Figure 3](#) for both azimuth and elevation in order to observe the behaviour of the scanner head beam position over the full range of azimuths.



**Figure 3 Azimuth and elevation offsets vs azimuth and its sinusoidal behaviour**

From these graphs one can see that the pitch and roll of a non-perfectly levelled device have a sinusoidal influence on both observed offsets. The goal remains to be precisely pointing at the mast with the correct azimuth and elevation angles.

Knowing the absolute azimuth angle necessary to reach the mast from the Sterenn position, the sinusoidal fit allows deducing, for both parameters, the offsets for the beams to point at the mast. The final step is to apply the CNR Mapping technique to the mast itself, find the necessary azimuth and elevation couple to reach the mast-top cup anemometer and wind vane from the scanner head reading (here it was -127.64;1.39), and then apply the above offsets for comparison of the radial wind speed to the measurements at the mast.

An example on azimuth correction: the scanner head finds the mast at -127.64 deg or again 232.36 deg, to which the azimuth offset interpolated at this direction (59.644 deg) is applied. This results in a final azimuth of 292.004 deg.

The final couple to use for projection of the cup anemometer and wind vane measurements on the Lidar LOS is then

Azimuth: 292.004 deg.

Elevation: 1.341 deg.

Finally, from the CNR Mapping, the precise range gate is found at which the backscatter intensity is maximum. Here it is 4600.56 m.

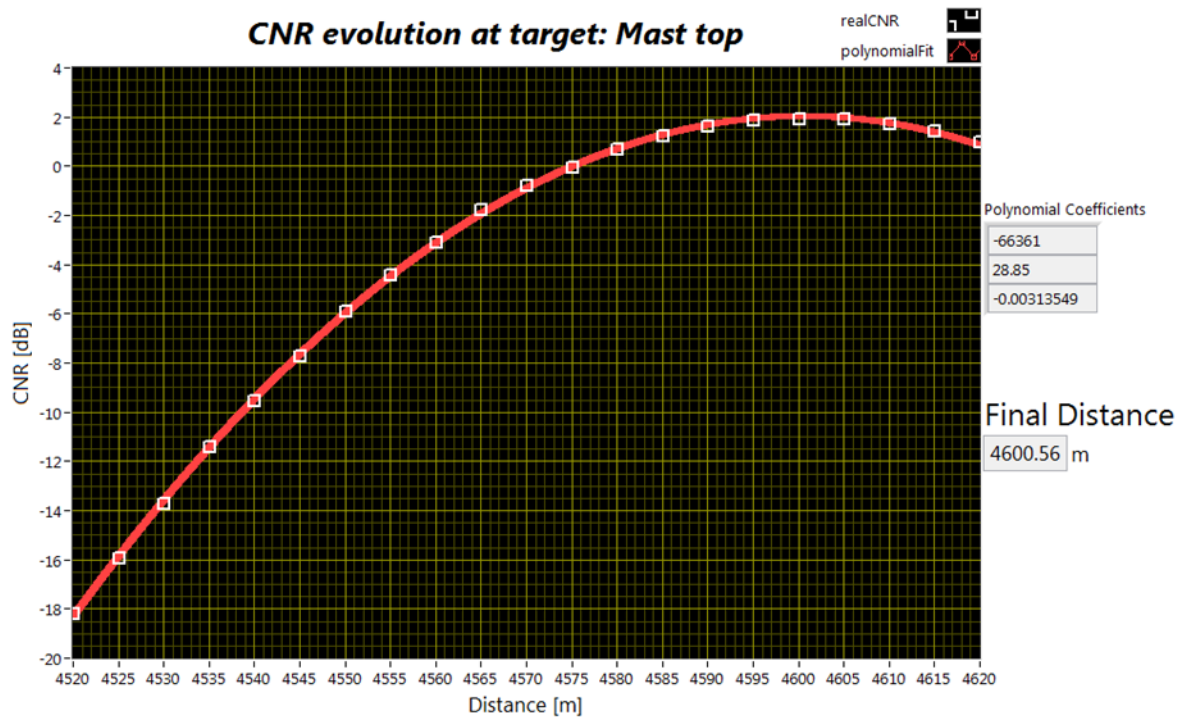


Figure 4 Backscatter intensity (CNR) with distance when the beam is pointing at the mast top

### 3. Results

The scanning lidars were measuring from the 18th of September 2015 until the 6th of October 2015 in a staring mode for lidar to mast comparison.

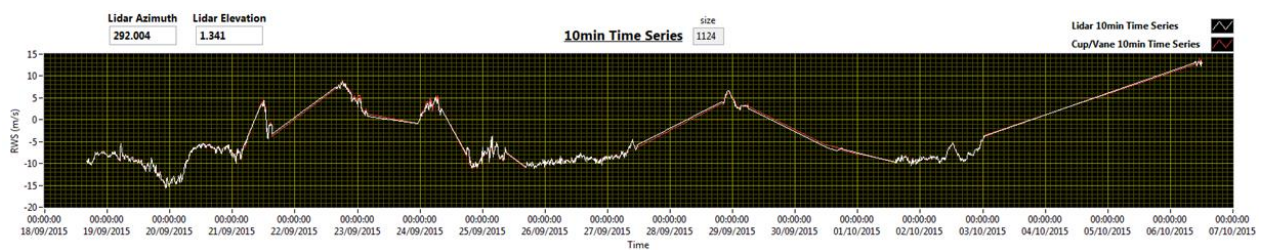
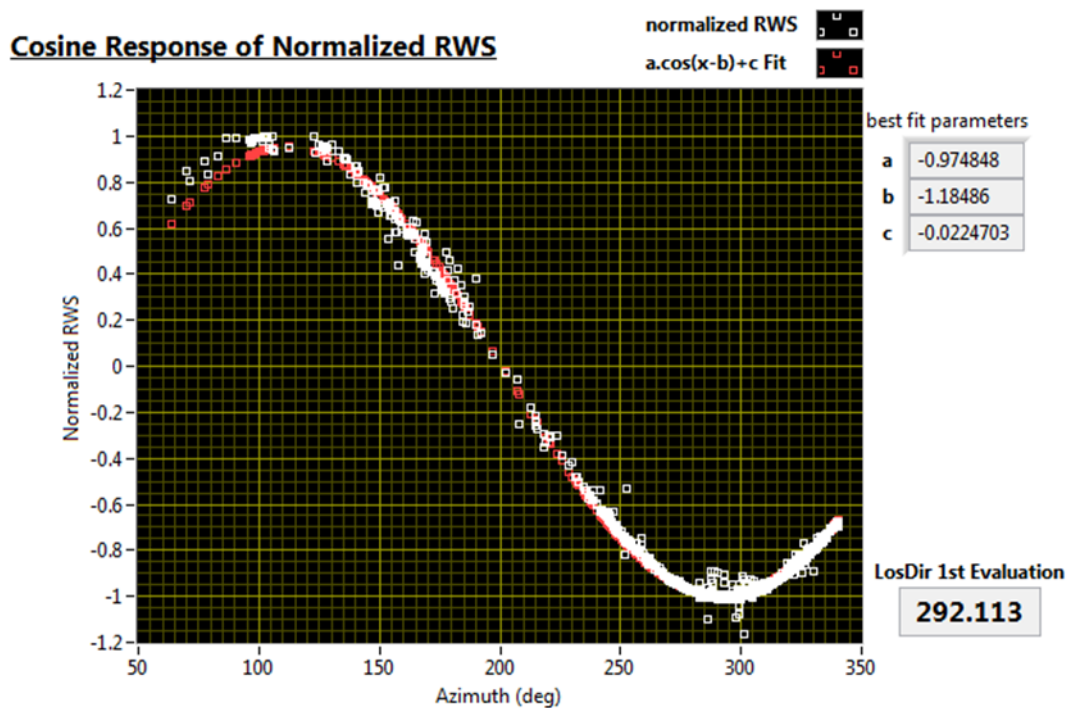


Figure 5 10-min time series of both the lidar radial wind speed (RWS) and the equivalent Cup/Vane RWS

The goal is to assess whether or not the previously deduced azimuth is correct by studying the cosine response of the normalized RWS in a 1st step.



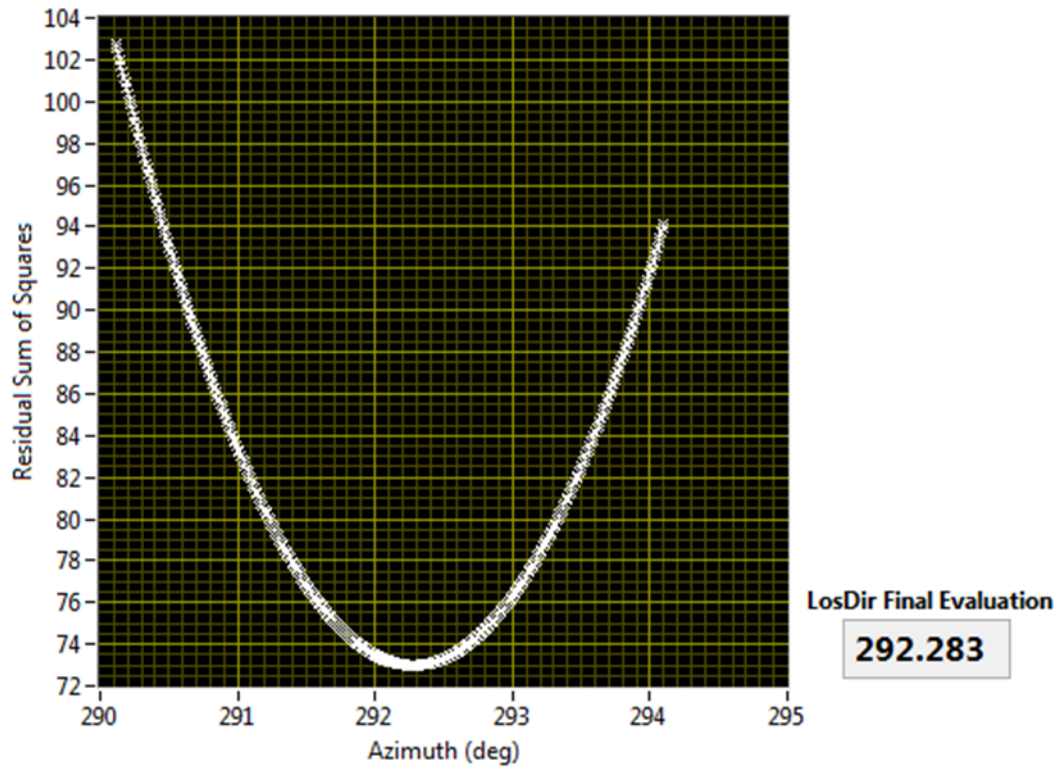
**Figure 6** Cosine response of the normalized RWS on 1124 points of a 10-min period

One can already see that the original deduced azimuth of 292.004 agrees very well with the above result giving the best match at 292.113.

The next step is to process a RWS correlation using a window of azimuth angles around this new value. The next figure shows the residual sum of squares (RSS) results from an azimuth varying from 292,113 +/- 2 deg. with a step of 0,01 deg..

## LOS Direction Final Evaluation

RSS vs Azimuth



**Figure 7** LOS direction final evaluation using RSS

The final LOS direction evaluation gives again a value of 292.283 deg., which corresponds very well to the original deduced one of 292.004 deg.,.

It is now confirmed that the deployment and alignment procedure, which relies on the combination of a hard target mapped by both the Leica and scanning lidar systems, gives a very good precision even when compared to a 5-km reference instrument.

Finally, the next figure shows the correlation result (between mast-derived and lidar RWSs) when using the final LOS direction value.

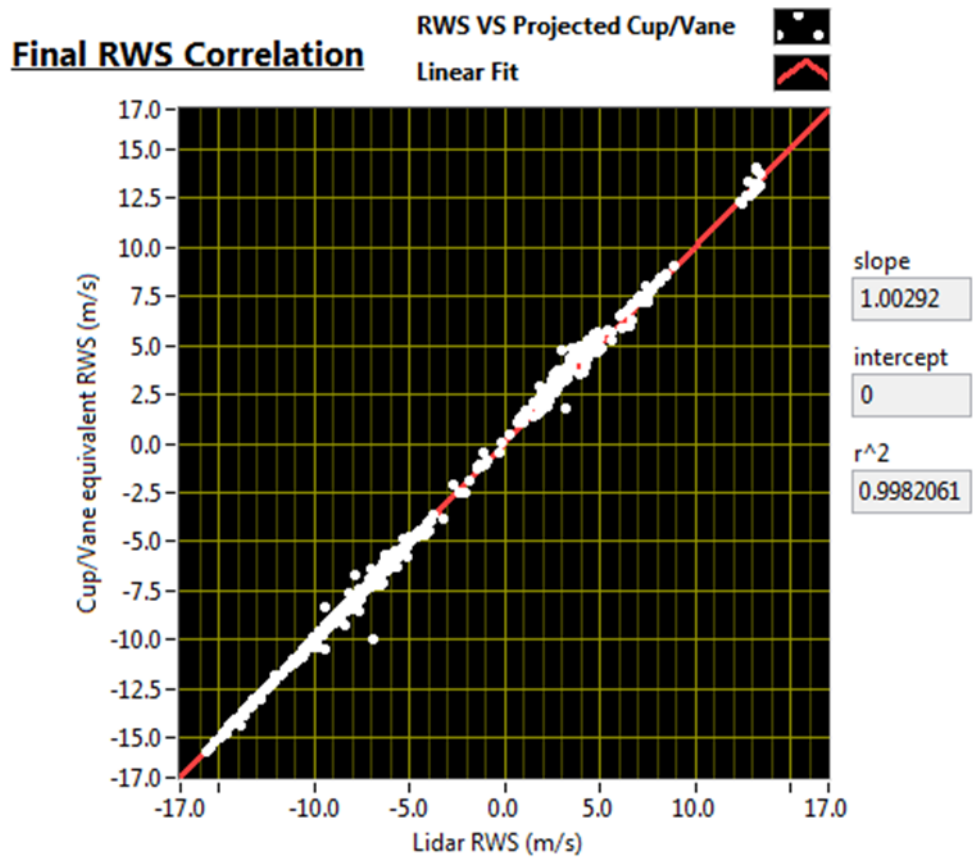


Figure 8 Final Lidar to Cup/Vane RWS correlation



## 4. Uncertainty of the radial wind speed

In this section, we will make an estimate of the uncertainty of the radial wind speed using the comparison to the traceable cup anemometer shown in [Figure 8](#)~~Figure-7~~ as the basis. Using an approach similar to that used for calibrating nacelle lidars, the uncertainty of the LOS speed  $U_{V_{los}}$  is given by

$$U_{V_{los}} = \sqrt{U_{V_{ref}}^2 + \frac{\sigma_{diff}^2}{N}}$$

This calculation is performed for each 0.5 m/s wind speed bin and the terms are defined as

- $U_{V_{ref}}$  is the uncertainty of the reference wind speed in the bin
- $\sigma_{diff}$  is the standard deviation of the difference between the lidar LOS speed and the reference LOS speed
- $N$  is the number of points in the bin.

The reference wind speed uncertainty  $U_{V_{ref}}$  is composed of a calibration uncertainty (*ref unc cal*), an operational (classification) uncertainty (*ref unc ope*) and a mounting uncertainty (*ref unc mount*). Values follow our current practice in nacelle lidar calibration as given in [4].

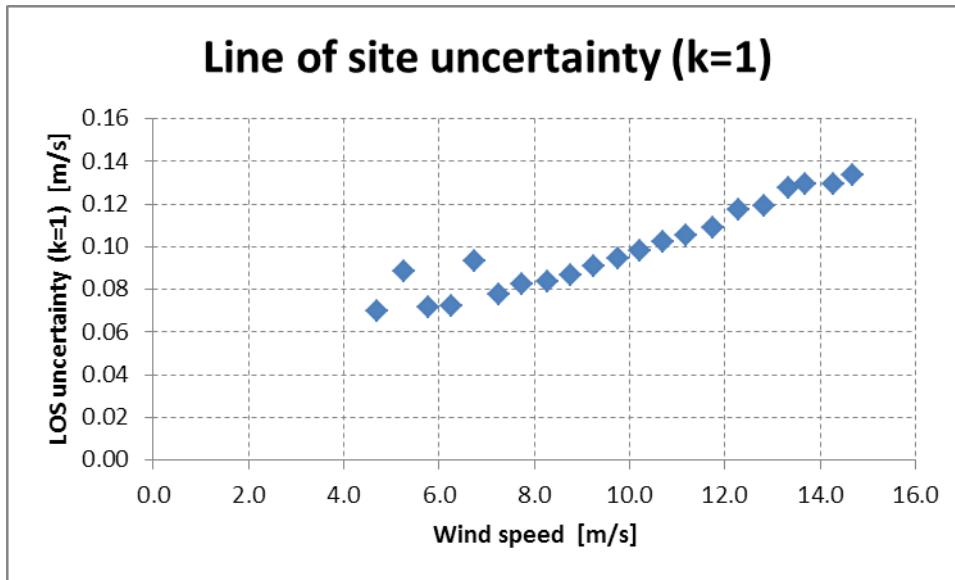
Uncertainties are calculated for the negative wind speed range shown in [Figure 8](#)~~Figure-7~~.

These are speeds towards the lidar, in this case, from the SW and W. Positive radial winds speeds for this deployment will generally be from easterly and north-easterly directions and include wakes from wind turbines. Furthermore for the RUNE campaign, we will primarily be measuring winds towards the lidar (negative radial speeds).

Standard uncertainties (coverage factor (k)=1) are shown in [Table 2](#)~~Table-2~~. It can be seen that in most cases the reference wind speed uncertainty (column *ref unc total*) is dominating. The absolute LOS uncertainty (column *los unc total*) is plotted as a function of bin mean speed in [Figure 9](#)~~Figure-8~~.

**Table 2 LOS uncertainties (k=1)**

Bin	Bin mean	Abs mean	N	avg diff	sigma diff	sigma diff over N	ref unc cal	ref unc ope	ref unc mount	ref unc total	los unc total	los unc %
-30	-14.7	14.7	9	0.02	0.07	0.02	0.09	0.06	0.07	0.13	0.13	0.91
-29	-14.3	14.3	12	0.04	0.05	0.01	0.09	0.06	0.07	0.13	0.13	0.90
-28	-13.7	13.7	15	-0.02	0.15	0.04	0.08	0.06	0.07	0.12	0.13	0.95
-27	-13.3	13.3	6	0.03	0.10	0.04	0.08	0.06	0.07	0.12	0.13	0.96
-26	-12.8	12.8	8	0.01	0.06	0.02	0.08	0.06	0.06	0.12	0.12	0.93
-25	-12.3	12.3	8	0.06	0.09	0.03	0.08	0.06	0.06	0.11	0.12	0.96
-24	-11.8	11.8	3	0.03	0.01	0.00	0.07	0.06	0.06	0.11	0.11	0.93
-23	-11.2	11.2	13	0.01	0.05	0.01	0.07	0.06	0.06	0.10	0.11	0.94
-22	-10.7	10.7	29	-0.07	0.10	0.02	0.07	0.05	0.05	0.10	0.10	0.96
-21	-10.2	10.2	55	0.00	0.09	0.01	0.06	0.05	0.05	0.10	0.10	0.96
-20	-9.7	9.7	104	0.02	0.10	0.01	0.06	0.05	0.05	0.09	0.09	0.97
-19	-9.3	9.3	129	0.04	0.15	0.01	0.06	0.05	0.05	0.09	0.09	0.98
-18	-8.8	8.8	128	0.03	0.08	0.01	0.06	0.05	0.04	0.09	0.09	0.99
-17	-8.3	8.3	97	0.00	0.14	0.01	0.05	0.05	0.04	0.08	0.08	1.02
-16	-7.7	7.7	76	-0.04	0.21	0.02	0.05	0.05	0.04	0.08	0.08	1.07
-15	-7.3	7.3	47	-0.01	0.13	0.02	0.05	0.04	0.04	0.08	0.08	1.07
-14	-6.7	6.7	54	-0.13	0.44	0.06	0.05	0.04	0.03	0.07	0.09	1.38
-13	-6.3	6.3	67	-0.07	0.18	0.02	0.04	0.04	0.03	0.07	0.07	1.15
-12	-5.8	5.8	35	-0.06	0.17	0.03	0.04	0.04	0.03	0.07	0.07	1.24
-11	-5.3	5.3	14	-0.10	0.24	0.06	0.04	0.04	0.03	0.06	0.09	1.68
-10	-4.7	4.7	9	-0.02	0.12	0.04	0.04	0.04	0.02	0.06	0.07	1.49



**Figure 9 Absolute LOS uncertainty (in m/s) at k=1**



## 5. Conclusion

Prior to the RUNE campaign, the pointing accuracy and radial wind speed accuracy of the scanning lidars was estimated at a 5-km range, corresponding to typical coastal measurements. The azimuth position of the mast found from hard targeting was within  $0.3^\circ$  of the value obtained from the alignment procedure.

The lidar radial wind speed was compared to the projected value from the mast top cup anemometer speed and the wind vane direction at 100 m. A regression analysis showed agreement within 0.2%.

Uncertainty of the radial wind speed has been calculated and found to be dominated by the reference cup anemometer uncertainty.

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**Danmarks Tekniske Universitet**

DTU Vindenergi  
Nils Koppels Allé  
Bygning 403  
2800 Kgs. Lyngby  
Telephone 45 25 25 25

[info@vindenergi.dtu.dk](mailto:info@vindenergi.dtu.dk)  
[www.vindenergi.dtu.dk](http://www.vindenergi.dtu.dk)